

Original Research

# Ecological Characteristics of Habitats Suitable for *Solidago* × *niederederi* Khek (Asteraceae) Establishment

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## Abstract

In this study, phytosociological plots are used to describe species composition and ecological conditions of habitats in which *Solidago* × *niederederi*, a natural hybrid between the North American *S. canadensis* and the European *S. virgaurea*, was found as established in Poland. Four groups of phytosociological plots have been distinguished based on the unweighted pair group method with arithmetic mean. The groups did not differ significantly in the mean number of species per plot and in the species evenness, in contrast to the mean values of Shannon-Wiener index and Simpson index. In each group of phytosociological plots, *S. ×niederederi* and *S. virgaurea* had the highest value of constancy degree. Meadow species of the class *Molinio-Arrhenatheretea* had the highest share in all groups of phytosociological plots. Considering the Ellenberg's indicators, the groups of phytosociological plots differed significantly in the mean values of the light and thermal conditions, soil moisture, soil reaction, and nutrients. The results suggested that *S. ×niederederi* can be established in well light places with partial shade and temperate conditions, on moist, moderately acidic to almost neutral soils with average fertility and is strongly associated with *S. virgaurea* and meadow species of *Molinio-Arrhenatheretea*.

**Keywords:** alien species, ecological indicators, hybrid, phytosociological plots

## Introduction

Natural hybridization between alien and native plant species reflects the consequences of introduction,

establishment and invasion of alien plants [1-8]. According to recommendation by Pyšek et al. [9], hybrids between alien and native plant species should be treated as alien species and they can pose a threat to native biodiversity [1-4]. In extreme cases, when hybridization between alien and native species is common in the wild and the hybrids are fully vigorous

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and fertile, pure native species cannot be recovered by removing the alien, resulting in replacement or local extinction of native species by introgressive hybridization [10]. It is commonly known that plant hybrids are usually found in disturbed habitats, as disturbance creates intermediate conditions in which hybrids can survive [2, 5]. However, the persistence of many plant hybrids is often limited by their sterility and non-fitness [11-12]. Phytosociological studies on habitat preferences of hybrids between alien and native plants are rarely undertaken [13]. Considering the need for nature conservation, it is important to determine the species composition of habitats in which such hybrids can occur and, what is more important, to evaluate their impacts on native biodiversity.

*Solidago ×niederederi* Khek (Asteraceae), a natural hybrid between the North American *S. canadensis* L. and the European *S. virgaurea* L., has been reported from several countries in Europe [14-19]. It is a perennial plant which spreads by wind-dispersed fruits (cypselas). However, the fruit set in the hybrid can be negatively affected by its reduced pollen viability [17, 20]. *Solidago ×niederederi* is considered as an established alien in Austria, Poland, Lithuania, and Latvia [19, 21]. According to Pliszko and Kostrakiewicz-Gierałt [22], the hybrid can pose a threat to native *S. virgaurea* by competing for pollinators. Moreover, there is a probability that the hybrid can cause genetic

erosion of *S. virgaurea* populations by introgressive hybridization. As currently known, *S. ×niederederi* occurs in anthropogenic habitats such as abandoned fields, roadsides, railway embankments, disused quarries, tree plantations, forest clearings, and arable fields with grass-legume mixtures, usually together with its parental species [7, 13-15, 23-25]. Moreover, Pliszko and Kostrakiewicz-Gierałt [23] evidenced that the most abundant populations of the hybrid in Poland were found on abandoned fields. Unfortunately, phytosociological studies on the habitats occupied by the hybrids have not been undertaken so far. Moreover, in the context of its establishment habitat requirements of *S. ×niederederi* are insufficiently recognized [17]. In this paper, we aimed to describe the conditions of habitats suitable for *S. ×niederederi* establishment, using phytosociological data.

## Materials and Methods

### Phytosociological Survey

The study was based on 90 phytosociological plots (relevés) of 25 m<sup>2</sup> made in agricultural landscape, at the altitude from 104 to 567 m above sea level, in north-eastern, central and southern parts of Poland, in 2013-2016 (Table 1), including vascular plant species

Table 1. Origin of phytosociological plots sampled for the study.

| Plot number | Name of Location        | GPS coordinates         | Altitude [m a.s.l.] | Habitat                  | Date of sampling |
|-------------|-------------------------|-------------------------|---------------------|--------------------------|------------------|
| 1           | Wysieka near Bartoszyce | 54°17.631'N/20°43.481'E | 104                 | Abandoned field          | 17 Aug 2013      |
| 2           | Kraków                  | 50°05.297'N/19°50.601'E | 241                 | Disused limestone quarry | 24 Aug 2013      |
| 3           | Kraków                  | 50°05.391'N/19°50.440'E | 226                 | Disused limestone quarry | 24 Aug 2013      |
| 4           | Kraków                  | 50°05.420'N/19°50.473'E | 229                 | Disused limestone quarry | 24 Aug 2013      |
| 5           | Kraków                  | 50°05.414'N/19°50.473'E | 230                 | Disused limestone quarry | 24 Aug 2013      |
| 6           | Kraków                  | 50°05.443'N/19°50.444'E | 228                 | Disused limestone quarry | 24 Aug 2013      |
| 7           | Izdebnik                | 49°51.972'N/19°43.986'E | 350                 | Abandoned field          | 29 Aug 2013      |
| 8           | Izdebnik                | 49°51.974'N/19°43.982'E | 350                 | Abandoned field          | 29 Aug 2013      |
| 9           | Izdebnik                | 49°51.995'N/19°44.156'E | 363                 | Abandoned field          | 29 Aug 2013      |
| 10          | Głogoczów               | 49°54.689'N/19°52.338'E | 241                 | Abandoned field          | 7 Sep 2013       |
| 11          | Wrzosey                 | 50°03.648'N/19°36.800'E | 308                 | Abandoned field          | 15 Sep 2013      |
| 12          | Wrzosey                 | 50°03.585'N/19°37.035'E | 331                 | Abandoned field          | 15 Sep 2013      |
| 13          | Suwałki                 | 54°04.528'N/22°57.068'E | 165                 | Abandoned field          | 18 Aug 2014      |
| 14          | Suwałki                 | 54°04.534'N/22°57.065'E | 165                 | Abandoned field          | 18 Aug 2014      |
| 15          | Suwałki                 | 54°04.529'N/22°57.076'E | 164                 | Abandoned field          | 18 Aug 2014      |
| 16          | Suwałki                 | 54°04.515'N/22°57.026'E | 165                 | Abandoned field          | 18 Aug 2014      |
| 17          | Suwałki                 | 54°04.505'N/22°56.998'E | 166                 | Abandoned field          | 18 Aug 2014      |
| 18          | Karasiewo               | 54°03.744'N/22°40.526'E | 163                 | Abandoned field          | 19 Aug 2014      |

Table 1. Continued.

|    |                           |                         |     |                 |             |
|----|---------------------------|-------------------------|-----|-----------------|-------------|
| 19 | Bakalarzewo               | 54°06.004'N/22°39.489'E | 169 | Abandoned field | 19 Aug 2014 |
| 20 | Bakalarzewo               | 54°05.964'N/22°39.560'E | 169 | Abandoned field | 19 Aug 2014 |
| 21 | Bakalarzewo               | 54°05.962'N/22°39.558'E | 168 | Abandoned field | 19 Aug 2014 |
| 22 | Bakalarzewo               | 54°05.958'N/22°39.538'E | 169 | Abandoned field | 19 Aug 2014 |
| 23 | Bakalarzewo               | 54°05.981'N/22°39.525'E | 169 | Abandoned field | 19 Aug 2014 |
| 24 | Mieruniszki               | 54°10.788'N/22°33.522'E | 191 | Abandoned field | 20 Aug 2014 |
| 25 | Taciewo                   | 54°09.287'N/22°48.435'E | 202 | Abandoned field | 21 Aug 2014 |
| 26 | Taciewo                   | 54°09.289'N/22°48.429'E | 203 | Abandoned field | 21 Aug 2014 |
| 27 | Czajowice                 | 50°11.444'N/19°48.554'E | 438 | Abandoned field | 29 Aug 2014 |
| 28 | Czajowice                 | 50°11.467'N/19°48.529'E | 440 | Abandoned field | 29 Aug 2014 |
| 29 | Czajowice                 | 50°11.487'N/19°48.507'E | 442 | Abandoned field | 29 Aug 2014 |
| 30 | Czajowice                 | 50°11.528'N/19°48.470'E | 443 | Abandoned field | 29 Aug 2014 |
| 31 | Czajowice                 | 50°11.461'N/19°48.403'E | 445 | Abandoned field | 29 Aug 2014 |
| 32 | Czajowice                 | 50°11.429'N/19°48.395'E | 448 | Abandoned field | 29 Aug 2014 |
| 33 | Czajowice                 | 50°11.128'N/19°48.421'E | 436 | Abandoned field | 29 Aug 2014 |
| 34 | Czajowice                 | 50°11.136'N/19°48.438'E | 436 | Abandoned field | 29 Aug 2014 |
| 35 | Czajowice                 | 50°11.142'N/19°48.433'E | 435 | Abandoned field | 29 Aug 2014 |
| 36 | Suwałki                   | 54°07.409'N/22°57.129'E | 178 | Abandoned field | 2 Sep 2014  |
| 37 | Suwałki                   | 54°07.398'N/22°57.132'E | 180 | Abandoned field | 2 Sep 2014  |
| 38 | Suwałki                   | 54°07.392'N/22°57.124'E | 179 | Abandoned field | 2 Sep 2014  |
| 39 | Suwałki                   | 54°07.392'N/22°57.124'E | 179 | Abandoned field | 2 Sep 2014  |
| 40 | Suwałki                   | 54°07.389'N/22°57.122'E | 179 | Abandoned field | 2 Sep 2014  |
| 41 | Kociołki near Pluszkiejmy | 54°17.415'N/22°27.762'E | 198 | Abandoned field | 7 Sep 2014  |
| 42 | Kociołki near Pluszkiejmy | 54°17.445'N/22°27.740'E | 193 | Abandoned field | 7 Sep 2014  |
| 43 | Kociołki near Pluszkiejmy | 54°17.451'N/22°27.804'E | 192 | Abandoned field | 7 Sep 2014  |
| 44 | Kociołki near Pluszkiejmy | 54°17.444'N/22°27.831'E | 194 | Abandoned field | 7 Sep 2014  |
| 45 | Kociołki near Pluszkiejmy | 54°17.442'N/22°27.835'E | 193 | Abandoned field | 7 Sep 2014  |
| 46 | Kociołki near Pluszkiejmy | 54°17.436'N/22°27.830'E | 194 | Abandoned field | 7 Sep 2014  |
| 47 | Kociołki near Pluszkiejmy | 54°17.448'N/22°27.887'E | 197 | Abandoned field | 7 Sep 2014  |
| 48 | Kociołki near Pluszkiejmy | 54°17.458'N/22°27.933'E | 198 | Abandoned field | 7 Sep 2014  |
| 49 | Kociołki near Pluszkiejmy | 54°17.398'N/22°27.926'E | 200 | Abandoned field | 7 Sep 2014  |
| 50 | Kociołki near Pluszkiejmy | 54°17.394'N/22°27.734'E | 196 | Abandoned field | 7 Sep 2014  |
| 51 | Łapczyca                  | 49°58.070'N/20°21.432'E | 282 | Abandoned field | 13 Sep 2014 |
| 52 | Warszawa Jeziorki         | 52°06.883'N/20°59.524'E | 106 | Abandoned field | 16 Sep 2014 |
| 53 | Warszawa Jeziorki         | 52°06.885'N/20°59.524'E | 106 | Abandoned field | 16 Sep 2014 |
| 54 | Warszawa Jeziorki         | 52°06.888'N/20°59.505'E | 106 | Abandoned field | 16 Sep 2014 |
| 55 | Warszawa Jeziorki         | 52°06.933'N/20°59.526'E | 106 | Abandoned field | 16 Sep 2014 |
| 56 | Warszawa Jeziorki         | 52°06.946'N/20°59.536'E | 106 | Abandoned field | 16 Sep 2014 |
| 57 | Zalesie Górne             | 52°01.483'N/21°00.685'E | 109 | Abandoned field | 17 Sep 2014 |
| 58 | Zalesie Górne             | 52°01.415'N/21°00.659'E | 109 | Abandoned field | 17 Sep 2014 |
| 59 | Zalesie Górne             | 52°01.412'N/21°00.664'E | 110 | Abandoned field | 17 Sep 2014 |

Table 1. Continued.

|    |                            |                         |     |                 |             |
|----|----------------------------|-------------------------|-----|-----------------|-------------|
| 60 | Zalesie Górne              | 52°01.408'N/21°00.667'E | 110 | Abandoned field | 17 Sep 2014 |
| 61 | Lipna Wola                 | 50°15.610'N/20°02.172'E | 268 | Abandoned field | 19 Sep 2014 |
| 62 | Lipna Wola                 | 50°15.609'N/20°02.177'E | 268 | Abandoned field | 19 Sep 2014 |
| 63 | Januszowice near Celiny    | 50°15.316'N/20°02.585'E | 293 | Abandoned field | 19 Sep 2014 |
| 64 | Miechów                    | 50°21.570'N/20°00.263'E | 304 | Balk            | 21 Sep 2014 |
| 65 | Budzów near Jachówka       | 49°45.096'N/19°40.636'E | 567 | Abandoned field | 30 Sep 2014 |
| 66 | Harbutowice near Sułkowice | 49°48.781'N/19°45.453'E | 536 | Abandoned field | 30 Sep 2014 |
| 67 | Harbutowice near Sułkowice | 49°48.778'N/19°45.416'E | 542 | Abandoned field | 30 Sep 2014 |
| 68 | Dąbrowskie Osada           | 54°03.221'N/22°33.467'E | 168 | Roadside ditch  | 1 Aug 2015  |
| 69 | Goldap                     | 54°17.870'N/22°18.505'E | 170 | Abandoned field | 6 Aug 2015  |
| 70 | Goldap                     | 54°17.881'N/22°18.534'E | 173 | Abandoned field | 6 Aug 2015  |
| 71 | Możne                      | 54°03.259'N/22°31.038'E | 163 | Abandoned field | 13 Aug 2015 |
| 72 | Możne                      | 54°03.231'N/22°30.983'E | 166 | Abandoned field | 13 Aug 2015 |
| 73 | Suwałki                    | 54°06.126'N/22°53.240'E | 177 | Abandoned field | 17 Aug 2015 |
| 74 | Suwałki                    | 54°06.079'N/22°53.153'E | 179 | Abandoned field | 17 Aug 2015 |
| 75 | Suwałki                    | 54°06.050'N/22°53.059'E | 176 | Abandoned field | 17 Aug 2015 |
| 76 | Suwałki                    | 54°06.054'N/22°53.020'E | 176 | Abandoned field | 17 Aug 2015 |
| 77 | Suwałki                    | 54°06.023'N/22°52.999'E | 180 | Abandoned field | 17 Aug 2015 |
| 78 | Las Garbaski               | 54°08.092'N/22°36.597'E | 178 | Forest clearing | 24 Aug 2016 |
| 79 | Dąbrowskie                 | 54°06.280'N/22°33.415'E | 189 | Roadside slope  | 25 Aug 2016 |
| 80 | Pieńki near Możne          | 54°03.585'N/22°30.532'E | 175 | Roadside ditch  | 25 Aug 2016 |
| 81 | Górne                      | 54°15.672'N/22°26.507'E | 180 | Abandoned field | 27 Aug 2016 |
| 82 | Wolbrom                    | 50°22.144'N/19°44.715'E | 395 | Abandoned field | 9 Sep 2016  |
| 83 | Wolbrom                    | 50°22.137'N/19°44.697'E | 394 | Abandoned field | 9 Sep 2016  |
| 84 | Wolbrom                    | 50°22.100'N/19°44.723'E | 389 | Abandoned field | 9 Sep 2016  |
| 85 | Podleśna Wola              | 50°24.704'N/20°00.923'E | 343 | Roadside slope  | 24 Sep 2016 |
| 86 | Podleśna Wola              | 50°24.487'N/20°01.200'E | 381 | Abandoned field | 24 Sep 2016 |
| 87 | Palcza                     | 49°49.231'N/19°44.665'E | 537 | Abandoned field | 1 Oct 2016  |
| 88 | Palcza                     | 49°49.269'N/19°44.614'E | 529 | Abandoned field | 1 Oct 2016  |
| 89 | Palcza                     | 49°49.485'N/19°44.413'E | 478 | Abandoned field | 1 Oct 2016  |
| 90 | Palcza                     | 49°49.591'N/19°44.253'E | 476 | Abandoned field | 1 Oct 2016  |

in accordance with the Braun-Blanquet method [26]. Initially, the hierarchical-numerical classification of phytosociological plots was performed using two methods, namely unweighted group pair method with arithmetic means (UPGMA) and weighted pair method with arithmetic means (WPGMA). The grouping of plots for each method was based on the presence/absence of species (0, 1 binary scale) and cover-abundance degree. In this way four dendrograms were obtained. However, only one dendrogram by the UPGMA method based on

the presence/absence of species [27] was used in this study. This classification allowed us to separate four groups of phytosociological plots that were the most consistent with field observations. The classification was performed using a SYN-TAX 2000 package [28]. The constancy degree and the cover coefficient were calculated for species occurring in the plots. Habitat conditions within the plots were characterized by the Ellenberg's indicator values [29, 30], using a JUICE package [31]. The mean values of indicators of light

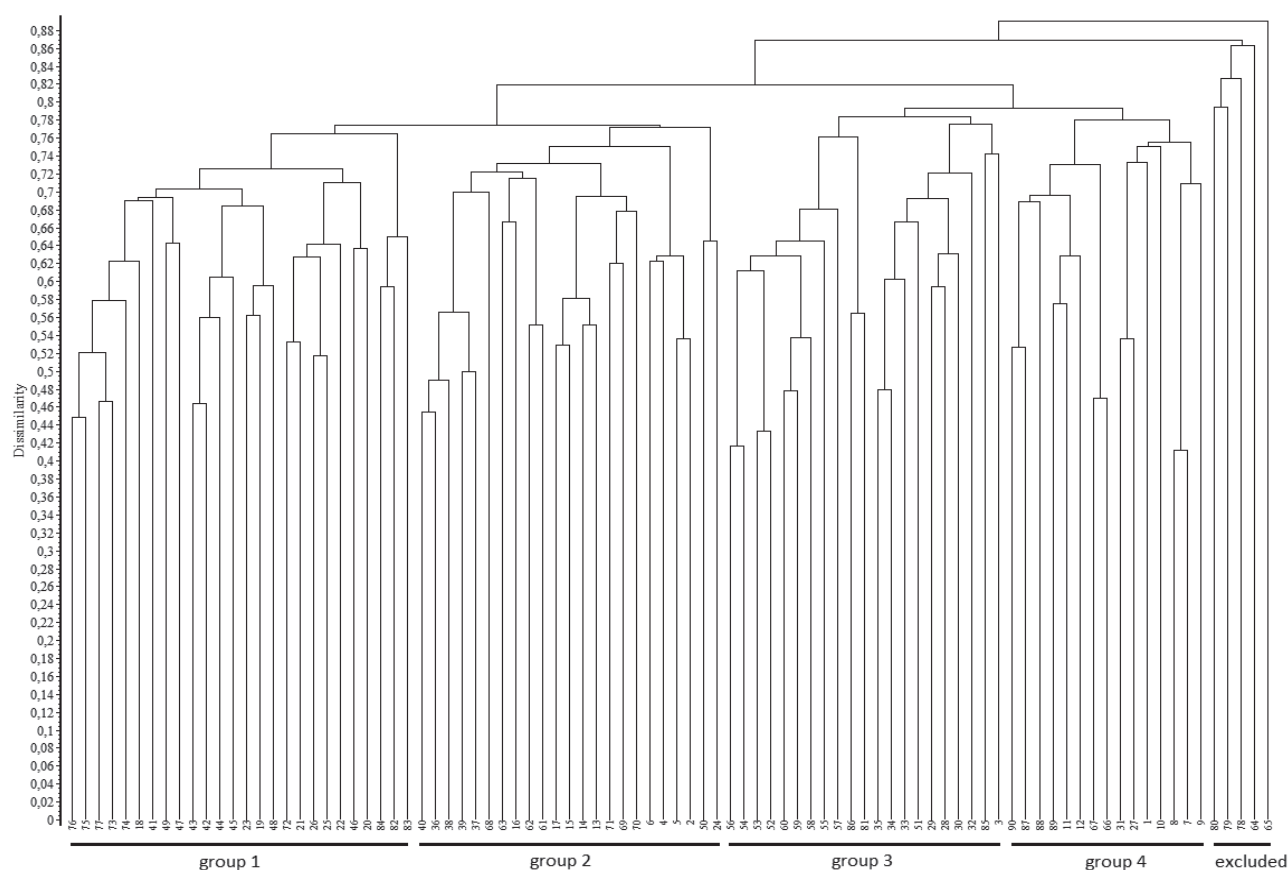


Fig. 1. Phytosociological plots grouping by UPGMA method.

conditions (L), thermal conditions (T), continentality (K), soil moisture (F), soil reaction (R), and nutrients (N) were calculated for the groups of phytosociological plots. To evaluate the diversity and quantitative relationships between the species in vegetation developed in different habitat conditions, the Shannon-Wiener index of diversity [32], species evenness [33], and Simpson index [34] were calculated as well. The affiliation of the species to syntaxonomic units followed Matuszkiewicz [35].

### Statistical Analysis

The normality of the untransformed data was tested using the Kolmogorov-Smirnov test, while the homogeneity of variance was checked using the Levene test at the significance level of  $P < 0.05$ . As the data in some groups were not consistent with the normal distribution and/or the variance was not homogeneous, the non-parametric Kruskal-Wallis  $H$  test was applied to check the statistical significance of differences in: (i) the number of species per plot, Shannon-Wiener index ( $H'$ ), species evenness ( $J'$ ), and Simpson index (SIMP) among particular groups of phytosociological plots and (ii) the values of Ellenberg's indicators among particular groups of phytosociological plots. The statistical analysis was performed using a STATISTICA 13 software.

### Results and Discussion

Based on the UPGMA method, four groups of phytosociological plots (1-4) were established, excluding the plots number 80, 79, 78, 64 and 65, in which floristic composition differed significantly from the others and which were not uniform in comparison to all data (Fig. 1). The groups consisted of 26, 23, 21 and 15 plots with 109, 118, 114 and 103 vascular plant species, respectively. The groups did not differ significantly in the mean number of species per plot and in the species evenness (Table 2). On the other hand, the differences in the mean values of Shannon-Wiener index and Simpson index between the groups were statistically significant (Table 2). The highest value of Shannon-Wiener index was evidenced in group 4, while the lowest was in group 3, whereas the highest value of Simpson index was evidenced in group 1, and the lowest in group 3 (Table 2).

Species having a value of constancy degree equal to III or higher for at least one of the four groups of plots are presented in Table 3. In each group of plots, *Solidago ×niederederi* and *S. virgaurea* had the highest value of constancy degree, whereas *S. canadensis* had the highest value of constancy degree only in groups 3 and 4 (Table 3). The values of the cover coefficient of *S. ×niederederi* were higher in groups 1 and 2 than in groups 3 and 4. Moreover, *S. virgaurea* had the highest

Table 2. Mean number of species per plot ( $\pm$ SD), Shannon-Wiener index ( $H'$ ), species evenness ( $J'$ ), and Simpson index (SIMP) in four groups of phytosociological plots with *Solidago ×niededereri*.

| Group of phytosociological plots          | Mean number of species per plot | $H'$                      | $J'$                       | SIMP                      |
|---|---------------------------------|---------------------------|----------------------------|---------------------------|
| 1   | 21.7 ( $\pm$ 4.3)               | 2.43 <sup>a</sup>         | 0.79                       | 0.85 <sup>a</sup>         |
| 2   | 22.2 ( $\pm$ 4.6)               | 2.36 <sup>ab</sup>        | 0.76                       | 0.81 <sup>ab</sup>        |
| 3   | 19.8 ( $\pm$ 3.5)               | 2.21 <sup>b</sup>         | 0.74                       | 0.79 <sup>b</sup>         |
| 4   | 23.3 ( $\pm$ 6.0)               | 2.44 <sup>ab</sup>        | 0.78                       | 0.84 <sup>ab</sup>        |
| The Kruskal-Wallis $H$ test;<br>$P$ value | $H=5.6$ ;<br>$P=0.13^{ns}$      | $H=9.2$ ;<br>$P\leq 0.05$ | $H=5.5$ ;<br>$P=0.13^{ns}$ | $H=8.0$ ;<br>$P\leq 0.05$ |

values of the cover coefficient in groups 1 and 4, whereas *S. canadensis* had the highest values of the cover coefficient in groups 3 and 4 (Table 3). Meadow species of the class *Molinio-Arrhenatheretea* had the highest share in all groups of plots. Floristic composition in groups 1 and 2 suggested more mesic soil habitats than those of groups 3 and 4. In group 1, *Dactylis glomerata* L. predominated together with other species of the class *Molinio-Arrhenatheretea* (i.e., *Arrhenatherum elatius* (L.) P. Beauv. ex J. & C. Presl and *Phleum pratense* L.).

Also, some ruderal species of the class *Artemisietea vulgaris* (i.e., *Artemisia vulgaris* L. and *Picris hieracioides* L.) and *Agrostis capillaris* L. of the class *Trifolio-Geranietea* had a high cover coefficient value in this group. Moreover, a thermophilic character of some phytosociological plots of group 1 was indicated by the presence of *Trifolium arvense* L. and *Senecio jacobaea* L. Similarly, in group 2, *Arrhenatherum elatius* and *Dactylis glomerata* predominated with a high share of two ruderal species of the class *Artemisietea vulgaris*

Table 3. Constancy degree (Cd) and cover coefficient (Cc) values of selected species in four groups of phytosociological plots with *Solidago ×niededereri*. Species having a value of constancy degree equal to III or higher for at least one of the four groups of plots are presented in this table.

| Group of phytosociological plots                                   | 1   |        | 2   |        | 3   |        | 4   |        |
|--|-----|--------|-----|--------|-----|--------|-----|--------|
| Constancy degree (Cd) and cover coefficient (Cc)                   | Cd  | Cc     | Cd  | Cc     | Cd  | Cc     | Cd  | Cc     |
| <i>Solidago ×niededereri</i> Khek                                  | V   | 250.0  | V   | 241.3  | V   | 71.4   | V   | 80.0   |
| <i>Solidago virgaurea</i> L.                                       | V   | 1084.6 | V   | 717.4  | V   | 754.8  | V   | 1493.3 |
| <i>Solidago canadensis</i> L.                                      | III | 592.3  | III | 497.8  | V   | 1109.5 | V   | 1360.0 |
| <b>ChCl. <i>Molinio-Arrhenatheretea</i></b>                        |     |        |     |        |     |        |     |        |
| <i>Achillea millefolium</i> L.                                     | V   | 244.2  | IV  | 39.1   | V   | 195.2  | V   | 216.7  |
| <i>Dactylis glomerata</i> L.                                       | IV  | 1394.2 | IV  | 1297.8 | II  | 278.6  | III | 773.3  |
| <i>Arrhenatherum elatius</i> (L.) P. Beauv. ex J. Presl & C. Presl | II  | 701.9  | IV  | 2978.3 | III | 1454.7 | I   | 150.0  |
| <i>Festuca rubra</i> L. s. l.                                      | II  | 242.3  | II  | 532.6  | III | 1133.3 | II  | 666.7  |
| <i>Rumex thyrsiflorus</i> Fingerh.                                 | IV  | 221.1  | III | 47.8   | III | 45.2   | II  | 13.3   |
| <i>Phleum pratense</i> L.  | III | 655.8  | II  | 47.8   | I   | 154.8  | I   | 150.0  |
| <i>Taraxacum</i> F.H. Wigg. sp.                                    | III | 290.4  | II  | 34.8   | I   | 83.3   | II  | 76.7   |
| <i>Poa pratensis</i> L.  | III | 101.9  | I   | 45.6   | I   | 285.7  | I   | 3.3    |
| <i>Galium mollugo</i> L.   | II  | 94.2   | III | 376.1  | I   | 47.6   | II  | 303.3  |
| <i>Knautia arvensis</i> (L.) J.M. Coult.                           | I   | 5.8    | III | 26.1   | I   | 2.4    | I   | 10.0   |
| <i>Vicia cracca</i> L.   | I   | 19.2   | III | 284.8  | II  | 33.3   | I   | 123.3  |
| <i>Holcus lanatus</i> L.   | I   | 19.2   | -   | -      | III | 492.8  | I   | 3.3    |
| <i>Ranunculus repens</i> L.  | -   | -      | -   | -      | I   | 47.6   | IV  | 296.7  |
| <i>Lysimachia vulgaris</i> L.                                      | -   | -      | I   | 2.2    | -   | -      | IV  | 263.3  |
| <i>Angelica sylvestris</i> L.                                      | -   | -      | -   | -      | I   | 23.8   | III | 86.7   |



Table 3. Continued.

| ChCl. <i>Trifolio-Geranietea</i>                       |     |        |     |       |     |       |     |        |
|--|-----|--------|-----|-------|-----|-------|-----|--------|
| <i>Agrostis capillaris</i> L.                          | IV  | 1298.1 | I   | 43.4  | III | 692.8 | V   | 2320.0 |
| <i>Galium verum</i> L.                                 | I   | 3.8    | III | 102.2 | II  | 38.1  | I   | 36.7   |
| ChCl. <i>Koelerio glaucae-Corynepherea canescentis</i> |     |        |     |       |     |       |     |        |
| <i>Trifolium arvense</i> L.                            | IV  | 355.8  | II  | 89.1  | -   | -     | I   | 33.3   |
| ChCl. <i>Artemisietea vulgaris</i>                     |     |        |     |       |     |       |     |        |
| <i>Artemisia vulgaris</i> L.                           | V   | 328.8  | V   | 293.5 | II  | 11.9  | I   | 70.0   |
| <i>Tanacetum vulgare</i> L.                            | I   | 67.3   | II  | 395.6 | IV  | 511.9 | II  | 523.3  |
| <i>Picris hieracioides</i> L.                          | IV  | 523.1  | III | 156.5 | I   | 26.2  | -   | -      |
| <i>Epilobium montanum</i> L.                           | III | 21.1   | I   | 6.5   | I   | 4.8   | II  | 46.7   |
| ChCl. <i>Agropyretea intermedio-repentis</i>           |     |        |     |       |     |       |     |        |
| <i>Convolvulus arvensis</i> L.                         | I   | 26.9   | IV  | 54.3  | I   | 9.5   | I   | 10.0   |
| <i>Equisetum arvense</i> L.                            | I   | 25.0   | III | 115.2 | II  | 40.5  | III | 83.3   |
| ChCl. <i>Nardo-Callunetea</i>                          |     |        |     |       |     |       |     |        |
| <i>Hieracium umbellatum</i> L.                         | II  | 225.0  | I   | 82.6  | V   | 902.4 | II  | 246.7  |
| ChCl. <i>Epilobietea angustifolii</i>                  |     |        |     |       |     |       |     |        |
| <i>Holcus mollis</i> L.                                | -   | -      | -   | -     | I   | 133.3 | IV  | 640.0  |
| Others   |     |        |     |       |     |       |     |        |
| <i>Erigeron annuus</i> (L.) Desf. s. str.              | IV  | 367.3  | IV  | 302.2 | II  | 123.8 | II  | 73.3   |
| <i>Hypericum perforatum</i> L.                         | III | 107.7  | II  | 10.9  | IV  | 97.6  | IV  | 383.3  |
| <i>Senecio jacobaea</i> L.                             | IV  | 126.9  | III | 43.5  | II  | 14.3  | -   | -      |
| <i>Pimpinella saxifraga</i> L.                         | I   | 1.9    | IV  | 223.9 | II  | 33.3  | I   | 10.0   |

(i.e., *Artemisia vulgaris* and *Tanacetum vulgare* L.). In contrast, a high share of *Holcus lanatus* L., *Ranunculus repens* L. and *Lysimachia vulgaris* L. in groups 3 and 4 suggested a more moist environment than in groups 1 and 2. In group 3, *Festuca rubra* L. and *Arrhenatherum elatius* predominated, whereas in group 4 *Dactylis glomerata* and *Festuca rubra* were the dominant species. Moreover, in groups 3 and 4 there was also a high share of *Tanacetum vulgare* (Table 3).

Considering the Ellenberg's indicators, the groups of phytosociological plots significantly differed in the mean values of the light and thermal conditions, soil moisture, soil reaction, and nutrients, while the differences in the mean value of continentality were non-significant (Table 4). In general, the results suggest that habitats occupied by the plants of the groups 3 and 4 were moister and less nutrient rich than those of the groups 1 and 2, and habitats

Table 4. Mean values ( $\pm$ SD) of Ellenberg's indicators in four groups of phytosociological plots with *Solidago ×niedereideri*.

| Group of phytosociological plots                    | Ellenberg's indicator values      |                                   |  |                                    |                                    |                                   |
|---|-----------------------------------|-----------------------------------|--|------------------------------------|------------------------------------|-----------------------------------|
|   | L                                 | T                                 | K  | F                                  | R                                  | N                                 |
| 1   | 7.00 ( $\pm$ 0.3) <sup>ab</sup>   | 5.79 ( $\pm$ 0.2) <sup>a</sup>    | 3.90 ( $\pm$ 0.5)                              | 4.64 ( $\pm$ 0.3) <sup>a</sup>     | 5.70 ( $\pm$ 0.9) <sup>ac</sup>    | 5.00 ( $\pm$ 0.9) <sup>ab</sup>   |
| 2   | 7.20 ( $\pm$ 0.3) <sup>a</sup>    | 5.51 ( $\pm$ 0.2) <sup>b</sup>    | 4.07 ( $\pm$ 0.6)                              | 4.65 ( $\pm$ 0.4) <sup>a</sup>     | 6.81 ( $\pm$ 0.3) <sup>b</sup>     | 5.55 ( $\pm$ 0.7) <sup>a</sup>    |
| 3   | 7.03 ( $\pm$ 0.4) <sup>ab</sup>   | 5.67 ( $\pm$ 0.3) <sup>ab</sup>   | 4.24 ( $\pm$ 0.7)                              | 4.83 ( $\pm$ 0.4) <sup>a</sup>     | 5.81 ( $\pm$ 0.9) <sup>c</sup>     | 4.86 ( $\pm$ 0.9) <sup>b</sup>    |
| 4   | 6.78 ( $\pm$ 0.4) <sup>b</sup>    | 5.68 ( $\pm$ 0.2) <sup>ab</sup>   | 3.98 ( $\pm$ 0.4)                              | 5.29 ( $\pm$ 0.4) <sup>b</sup>     | 4.99 ( $\pm$ 0.7) <sup>c</sup>     | 4.88 ( $\pm$ 0.7) <sup>b</sup>    |
| The Kruskal-Wallis <i>H</i> test;<br><i>P</i> value | <i>H</i> =10.0;<br><i>P</i> ≤0.05 | <i>H</i> =14.4;<br><i>P</i> <0.01 | <i>H</i> =2.8;<br><i>P</i> =0.42 <sup>ns</sup> | <i>H</i> =22.5;<br><i>P</i> <0.001 | <i>H</i> =37.2;<br><i>P</i> <0.001 | <i>H</i> =11.1;<br><i>P</i> ≤0.05 |

Explanations: L – light conditions, T – thermal conditions, K – continentality, F – soil moisture, R – soil reaction, N – soil fertility (nutrients). The diverse letters in superscript indicate the significant differences between the samples.

occupied by the plants of group 4 were the most acidic (Table 4).

In Europe, habitat preferences of *Solidago canadensis* seem to be very different from those of *S. virgaurea*; however, both species can be found in close proximity in disturbed habitats, where their hybrid also occurs. According to Mucina [36], *S. canadensis* is a diagnostic species of nitrophilous synanthropic herb-rich communities of shaded woodland and riparian fringes of *Galio-Urticetea*. It is also known from ruderal communities of *Artemisietea vulgaris* [37]. In contrast, *S. virgaurea* occurs in conifer and mixed forests (e.g., *Peucedano-Pinetum*, *Betulo-Quercetum*, *Carici fritschii-Quercetum roboris*, *Galio odorati-Fagenion*), on fringes of temperate woodlands (*Trifolion medii*), in woodland clearings (*Epilobietea angustifolii*), as well as in meadow and grassland vegetation (e.g., *Arrhenatheretum elatioris*, *Scabioso canescentis-Genistetum*, *Koelerion glaucae*) [35, 37-39]. Moreover, Szymura and Szymura [40] demonstrated that in south-western Poland, *S. virgaurea* was associated with typical forest and acidophilous species such as *Vaccinium myrtillus* L., *Oxalis acetosella* L., and *Hieracium murorum* L., whereas *S. canadensis* occurred mostly with ruderal species such as *Artemisia vulgaris* and *Tanacetum vulgare*.

In this study, we showed that *S. ×niederederi* and *S. virgaurea* occur equally in all observed moisture levels whereas the abundance of *S. canadensis* is shifted towards more moist environment and the hybrid is mostly associated with meadow plant species of *Molinio-Arrhenatheretea*. It should be mentioned that the majority of phytosociological plots with *S. ×niederederi* were taken on abandoned fields (Table 1) and they mainly represented the early stages of secondary succession. The vegetation in such places is difficult to classify and usually has a temporary character. During the early stages of secondary succession on abandoned fields, many segetal, ruderal, meadow, and grassland species find suitable conditions for their growth [e.g., 41, 42]. The occurrence of *S. canadensis* and *S. virgaurea* on abandoned fields has been well documented in Poland and other European countries [40, 43-45]. Moreover, Rola and Rola [46] pointed out that *Solidago* species are bioindicators of fallow lands and they usually achieved a high cover on abandoned fields after 5-10 years from the abandonment.

Studies of many authors confirmed that plant communities dominated by alien *Solidago* species are characterized by much lower species richness and a decline in biodiversity [44, 47-48]. In our study, the values of Shannon-Wiener index (Table 1) were similar to those observed in segetal plant communities of *Stellarietea mediae* in Central Pomerania [49] and Lower Silesia [50]. It should be emphasized that the general biodiversity of plant communities with *S. canadensis* depends on the extent of its invasion – the greater the share of *S. canadensis*, the lower the value of Shannon-Wiener index [44, 48]. In our study, the

species evenness and Simpson index achieved the higher values compared to the results obtained for abandoned meadows [51], segetal plant communities of *Stellarietea mediae* and ruderal plant communities of *Artemisietea vulgaris* [49-50]. Generally, the values of Ellenberg's indicators in habitats with *S. ×niederederi* were similar to those evidenced on fallow lands with *S. canadensis* and *S. gigantea* Aiton [49, 51]. However, Bielecka et al. [52] noticed that *S. canadensis* grows on diverse habitats from strongly acidic to alkaline. Moreover, field studies in Lithuania revealed that *S. canadensis*, *S. gigantea* and *S. ×niederederi* can occupy similar soils with slightly lower pH [17]. Since the hybrid is on the early stage of its establishment and spread in Poland a further research is needed to confirm its association with meadow communities.

## Conclusions

*Solidago ×niederederi* can be established in well light places with partial shade and temperate conditions, on moist, moderately acidic to almost neutral soils with average fertility. It is strongly associated with *S. virgaurea* and meadow species of *Molinio-Arrhenatheretea*.

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## Conflict of Interest

The authors declare no conflict of interest.

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